

The background of the slide is a composite image of space exploration. On the left, a large, detailed Earth's moon is shown in a dark blue-grey color. Above it and to the left is a smaller, reddish-orange sphere, likely Mars. A small spacecraft is depicted in the upper left, emitting a bright blue beam of light that extends towards the center. The sky is a deep blue with numerous white stars. In the bottom right, the black silhouette of a person's head and shoulders is visible, looking towards the left. The overall theme is space exploration and technology.

EXPLORESpace TECH

TECHNOLOGY DRIVES EXPLORATION

EXPLORE: Advanced Avionics
NASA Space Technology Mission Directorate
August 2022

STMD welcomes feedback on this presentation

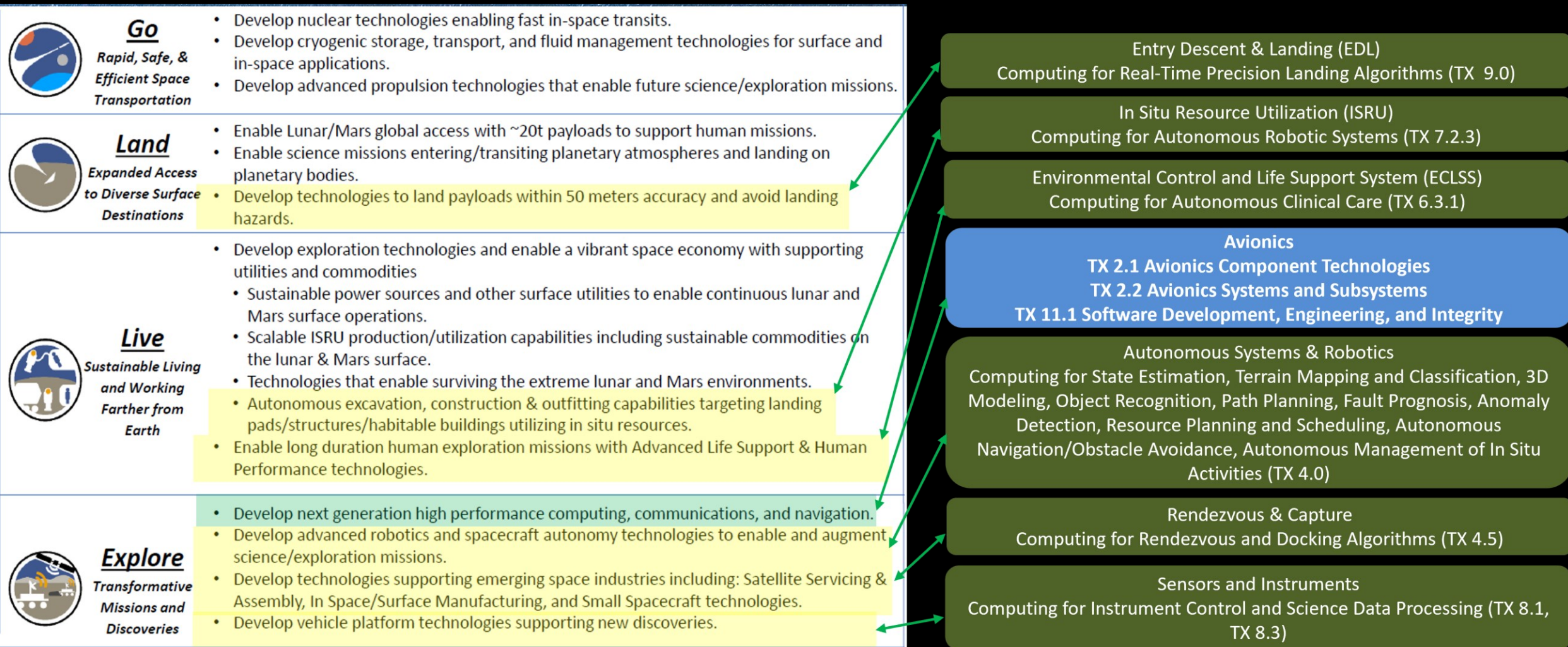
See 80HQTR22ZOA2L_EXP_LND at nspires.nasaprs.com for how to provide feedback

If there are any questions, contact HQ-STMD-STAR-RFI@nasaprs.com

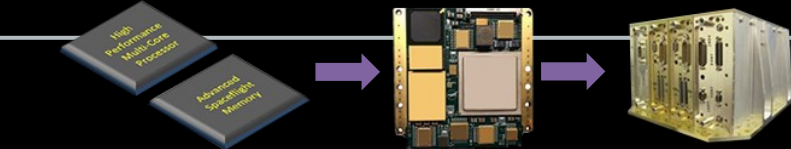
EXPLORE: Develop next generation high performance computing, communications, and navigation



Developing flight computing architectures and advanced avionics to enable increased onboard intelligence and autonomy for future exploration missions in harsh environments



Advanced Avionics – Envisioned Future



HIGH PERFORMANCE SPACEFLIGHT COMPUTING

- Radiation-hardened general-purpose processor with increased performance and flexibility to adapt to mission specific performance, power, and fault tolerance needs
- Advanced spaceflight memory with radiation tolerance and increased capacity and performance
- Intelligent, efficient, multiple output Point-Of-Load (POL) power converters
- High performance Single Board Computer (SBC) incorporating high-performance general-purpose processors, advanced memory, point-of-load converters, and real-time operating system in industry standard form factors and bus architectures
- System software tools to leverage the capabilities and manage the complexity of advanced multi-core processors



INTERCONNECT

- Radiation-tolerant interconnects to support low latency onboard video, multi-gigabit instruments, onboard science, and enhanced autonomy applications; including end points, switches, physical layer devices, and software support
- Highly reliable, high-bandwidth deterministic wireless networks



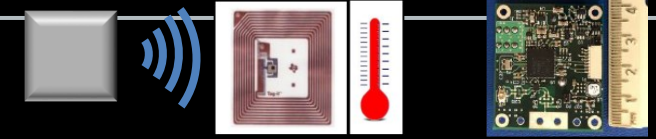
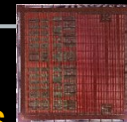
CREW INTERFACES

- Radiation-tolerant displays that can operate reliably for long durations mission beyond LEO
- Radiation-tolerant graphics processing that can operate reliably for long mission durations beyond LEO
- Heads Up Displays for Exploration EVA
- Crew voice and audio systems for deep space missions providing efficient compression of multiple streams, acoustic echo and noise cancellation, speech recognition and voice control, and wireless capabilities



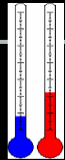
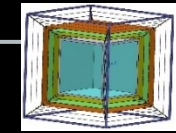
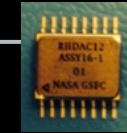
OTHER COMPUTING ARCHITECTURES

- Artificial Intelligence (AI) coprocessors to enable autonomous landing, surface navigation, robotic servicing/assembly, fault detection/mitigation, distributed systems operations, science data processing, and tip and cue for remote sensing missions
- Spaceflight quantum computers
- Low power embedded computers to support distributed robotics architectures



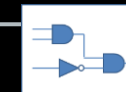
DATA ACQUISITION

- Wireless sensor networks to reduce harness mass and complexity, simplify integration and test, and improve system flexibility, serviceability, and expandability
- Low-cost, robust, high-accuracy data acquisition systems to enable distributed in situ monitoring of structures and subsystems on cost constrained missions



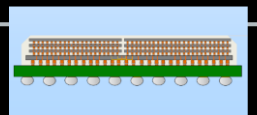
EXTREME ENVIRONMENT AVIONICS

- Extreme temperature electronics capable of operating in environments with both high radiation and wide temperature ranges, including lunar/planetary surfaces and nuclear systems
- Avionics packaging and thermal management technologies to enable avionics operation in extreme environments

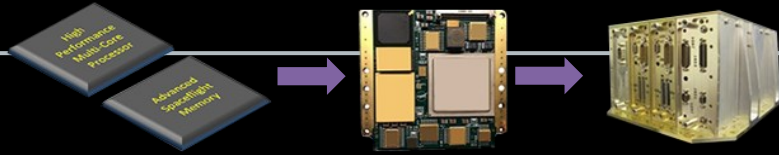


FOUNDATIONAL TECHNOLOGIES

- Advanced 2.5D/3D packaging and heterogeneous integration enabling miniaturization and improved performance
- Advanced semiconductor process nodes and libraries to enable next generation radiation hard devices
- Low-cost, radiation-hardened mixed-signal ASICs



Advanced Avionics – State of the Art



HIGH PERFORMANCE SPACEFLIGHT COMPUTING

- Processors – Current missions either using radiation-hardened processors with limited performance, or higher performance redundant COTS-based processors limiting power efficiency
 - Target - 3-5X performance improvement over current space processors for general purpose processing (GPP), parallel processing acceleration, and flexibility to adapt performance, power, and fault tolerance to mission needs*
- Memory – Radiation-hardened memories lack capacity and/or performance, while COTS-based memories are susceptible to radiation induced upsets
 - Target - Radiation-hardened memory with 4-8X the capacity and/or performance of existing radiation-hardened memories*
- Point-Of-Load (POL) Power Converters – Current POL converters provide a limited number of outputs and lack embedded fault tolerance
 - Target - Radiation-hardened, high efficiency POL converters with at least 3 outputs, bus interface, and embedded fault tolerance*
- Single Board Computer (SBC) – Current SBCs using radiation-hardened processors have limited performance, and limited capability for power and performance scaling
 - Target - Radiation-hardened SBC in industry standard form factor with 5X GPP improvement, parallel processing, and ability to scale power and performance*
- HPSC Software Tools – Current system software tools do not support the complexity of the High Performance Spaceflight Processing (HPSC) multicore processor
 - Target - System software tools that allow developers to fully leverage the GPP and parallel processing capabilities and flexibility of the HPSC processor*

INTERCONNECT



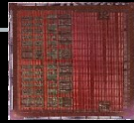
- Wired – Current onboard wired networks lack bandwidth to support increased sensor data rates of future missions
 - Target - Wired networks with 10X bandwidth improvement*
- Wireless – Current onboard wireless networks only support low criticality needs
 - Target - Wireless networks for critical applications in crewed and robotic missions*

CREW INTERFACES



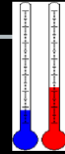
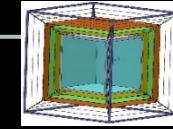
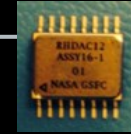
- Crew Displays and Graphics Processors – Current spaceflight technologies offer limited visual performance and have uncharacterized radiation risks for long duration missions beyond LEO
 - Target - Radiation-tolerant displays and graphics processors that can support displays with minimum of 1080p 30fps for Lunar and Mars mission durations (note - graphics processors are also applicable for other onboard processing functions)*
- Crew Voice and Audio Systems – Current system offer limited system performance and have uncharacterized radiation risks for long duration missions beyond LEO
 - Target - Radiation-hardened system with efficient compression, speech recognition and voice control, and active noise control for Lunar and Mars mission durations*

Advanced Avionics – State of the Art



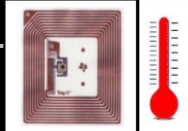
OTHER COMPUTING ARCHITECTURES

- Artificial Intelligence (AI) Coprocessors – COTS devices exist, but with unknown radiation performance and applicability to NASA onboard processing tasks
 - *Target - Radiation-tolerant AI coprocessors for NASA missions*
- Quantum Computing – Quantum computing technology is emerging, but is limited to terrestrial applications
 - *Target – Quantum computers tailored for onboard processing applications and environments*
- Low Power Embedded Computers – Current spaceflight robotics systems employ centralized architectures, which increases network bandwidth, latency, power, and system complexity
 - *Target – Low power embedded computers enabling distributed architectures*



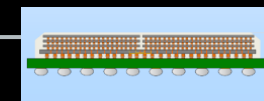
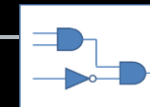
EXTREME ENVIRONMENT AVIONICS

- Extreme Temperature/Radiation Electronics – Only limited functions have been implemented that can operate in environments with both high radiation and wide temperature ranges, including lunar/planetary surfaces and nuclear systems
 - *Target – Diverse set of circuit functions to enable systems that can operate in Lunar surface, planetary surface, and nuclear systems environments with both high radiation and wide ranges of operating temperatures*
- Packaging and Thermal Management Technologies – Current approaches limit the ability to operate at extreme cold and hot temperatures
 - *Target - Packaging and thermal management technologies that can be tailored to operate across wide temperature ranges for Lunar or planetary missions*



DATA ACQUISITION

- Wireless sensor networks – Current onboard sensing requires harnessing, which incurs a mass penalty
 - *Target - Readout systems and diverse onboard wireless sensor node types*
- Data Acquisition (DAQ) Systems – Current entry descent and landing DAQ systems are too costly to deploy on wide range of missions
 - *Target - 10X cost reduction for distributed in situ monitoring of structures and subsystems on cost constrained missions*



FOUNDATIONAL TECHNOLOGIES

- Advanced 2.5D/3D Packaging and Heterogeneous Integration (HI) – These exist in industry, but lack spaceflight qualification
 - *Target - Qualified 2.5D/3D packaging and HI for NASA missions*
- Advanced Semiconductor Process Nodes/Libraries – Existing 45nm RHBD libraries lack the density and performance needed for next generation of computing devices
 - *Target - Libraries with 2X/4X the performance/density existing RHBD libraries*
- Low-Cost Mixed Signal ASICs – Custom mixed-signal ASIC NRE cost limits infusion
 - *Target - Radiation-hardened structured ASIC platforms to reduce NRE cost*

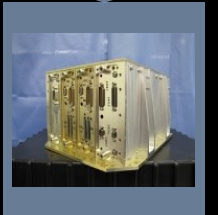
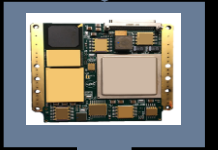
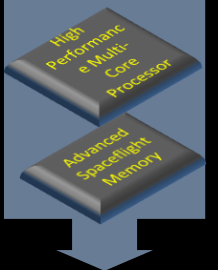
Advanced Avionics Gap Closure Plans

(**Green** =Funded, **Yellow** = Partially Funded, **Red** = Unfunded)



HIGH PERFORMANCE SPACEFLIGHT COMPUTING

Radiation-hardened general-purpose processor	Define a High Performance Spaceflight Computing (HPSC) processor concept that maximally leverages microelectronics technology advances for high reliability applications. Engage industry to develop and commercialize a radiation-hardened multi-core HPSC processor that addresses the computing needs of future NASA missions and broader markets. Leverage other government computing investments, as well as COTS developments, that are suitable for NASA use.
Advanced spaceflight memory	Fund the development and qualification of radiation-hardened non-volatile memory. Leverage other government agency investments in development of other radiation-hardened memory devices. Test emerging COTS memory technologies and identify devices that are suitable for NASA applications.
Point-Of-Load (POL) power converters	Leverage SBIR to develop intelligent, radiation-hardened multi-output POL converters that leverage industry smart power bus standards. Secure program funding for post Phase II commercialization.
Single Board Computer (SBC)	Define advanced avionics architectures that leverage HPSC capabilities. Develop spaceflight computer boards to demonstrate in those architectures. Engage industry to develop and commercialize spaceflight HPSC SBCs in industry standard form factors.
HPSC Software Tools	Port real-time operating systems, develop tools, and HPSC Middleware tools to support the full HPSC architecture. Assess existing libraries for image processing, signal processing, and machine learning, and augment as needed for HPSC architecture.



INTERCONNECT

Radiation-tolerant interconnect	Leverage the HPSC concept studies and the NESC SpaceVPX Interoperability Study to select optimal interconnect standards for further development. Engage with standards organizations to ensure that evolution of selected standards meet future NASA mission needs. Assess availability of components required (i.e. endpoints, switches, physical-layer components) for a robust ecosystem for the selected standards, and leverage SBIR to develop needed components.
Highly reliable, high bandwidth deterministic wireless networks	Engage academic institutions to develop novel techniques that extend the capabilities of space-based wireless networks in time-sensitive and safety-critical applications. Leverage SBIR/STTR as a follow on to implement for space flight demonstration.



Advanced Avionics Gap Closure Plans

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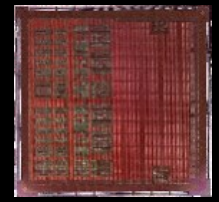
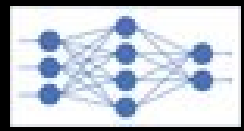
CREW INTERFACES

Radiation-tolerant displays	Under ESDMD Polaris project, characterize the radiation performance of candidate display pixel technologies and support circuitry. Transfer knowledge from Polaris project to industry for development and commercialization of radiation-tolerant displays for future NASA exploration missions.
Radiation-tolerant graphics processing	Engage small business to characterize radiation performance of COTS Graphics Processor Units (GPUs) and develop system-level radiation mitigation approaches suitable for use in future NASA exploration missions. Specifically, develop system-level mitigation approaches for transient errors due to single event effect (SEE).
Heads Up Display (HUD) Optics	Advance development of Heads Up Display (HUD) optics under ESDMD Polaris project to advance xEMU displays. Continue development efforts for xEMU partnering with academia and industry.
Crew voice and audio systems	Engage, current NASA programs, industry partners, and small business to develop systems that can meet future mission environments and incorporate speech recognition capabilities.



OTHER COMPUTING ARCHITECTURES

Artificial Intelligence (AI) coprocessor	Evaluate viability of COTS coprocessor devices and foundational technologies for NASA AI applications within the RadNeuro and the NEPP programs. Devise system-level radiation mitigation approaches to address susceptibilities in COTS devices. Demonstrate coprocessors and mitigation approaches via ground radiation testing and flight demonstrations. Study the optimal mapping of onboard (AI) applications to candidate processing architectures and devices.
Quantum Computing	Explore candidate use cases for onboard quantum computing and compare performance with other computing technologies. Assess radiation susceptibilities of quantum computing and potential mitigations. Define concept for spaceflight quantum computer, and develop prototype.
Low power embedded computers	Develop distributed avionics architecture to enable modular, interoperable, and reusable robotic systems. Define low power embedded computer concepts that are consistent with that architecture and can meet SWaP and extreme environmental requirements. Perform NASA development of proof-of-concept low power embedded computer, and then engage small business for further development and commercialization.



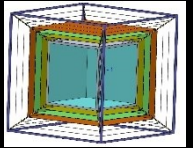
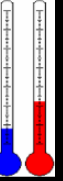
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EXTREME ENVIRONMENT ELECTRONICS

Extreme temperature/radiation electronics	Under the SMD ColdTech and HOTTech programs and STMD LSII and LuSTR programs, develop and characterize radiation-hardened extreme temperature design libraries in SiGe and SiC and implement digital and mixed-signal devices for infusion into NASA missions. Assess extreme temperature electronics from other industries for potential NASA use.
Avionics packaging and thermal management for extreme environments	Under the STMD PALETTE project, develop set of packaging and thermal management technologies to that avionics developers can utilize to implement passively controlled packaging for widely ranging mission environments. Infuse PALETTE technologies into lunar and planetary instruments and subsystems.



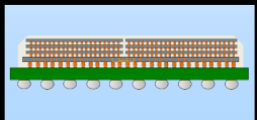
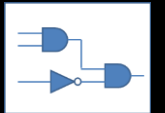
DATA ACQUISITION

Wireless sensor networks	Develop and demonstrate enhanced wireless sensor nodes with an implementation path for hardware that can operate reliably in harsh environments and demonstration in testing, support, and flight applications as needed. Specific solutions for crewed missions may be compatible with the Radio-frequency identification (RFID) Enabled Autonomous Logistics Management (REALM) system, leveraging additive manufacturing technology to provide miniaturization.
Low-cost, robust, high-accuracy data acquisition systems	Leverage SBIR to develop a radiation-tolerant low-cost data acquisition system technology. Secure program funding for post Phase II commercialization.



FOUNDATIONAL TECHNOLOGIES

Advanced 2.5D/3D packaging and heterogeneous integration	Develop conventional and additively manufactured 2.5D and 3D packaging technologies for low production volume devices. Engage Nextflex consortium to develop qualification methods for additively manufactured spaceflight electronics, and then demonstrate on smallsat missions. Engage industry on the development of qualification methods for 3D packaging.
Advanced Semiconductor Process Nodes/Libraries	Under NASA STMD funding, perform radiation characterization and modelling of the Global Foundries 22FDX process and automotive grade design libraries. Leverage other government and industry efforts in radiation-hardened deep submicron processes and libraries.
Low-Cost Mixed Signal ASICs	Engage industry to develop radiation-hardened mixed-signal structured ASIC platform to broadly meet NASA mission needs.



Advanced Avionics – Next Steps for Currently Unfunded Technologies



HIGH PERFORMANCE SPACEFLIGHT COMPUTING

- | | |
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| • Leverage SBIR to develop intelligent, radiation-hardened multi-output POL converters that leverage industry smart power bus standards. | Priority 2 |
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CREW INTERFACES

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| • Assess radiation susceptibilities and mitigations, and engage industry to develop and commercialize radiation-tolerant displays for future NASA exploration missions and crew voice and audio systems for future NASA exploration missions | Priority 1 |
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INTERCONNECT

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| • Engage with standards organizations to ensure that evolution of selected standards meet future NASA mission needs | Priority 3 |
| • Leverage SBIR to develop technologies needed (i.e., endpoints, switches, physical components) for a robust ecosystem that supports the selected standards | Priority 7 |
| • Engage academia to extend wireless network technology to meet the reliability and determinism needed by NASA applications for both crewed and robotic missions | Priority 8 |

LOW POWER EMBEDDED COMPUTER

- | | |
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| • Develop distributed avionics architecture to enable modular, interoperable, and reusable robotic systems | Priority 4 |
| • Define low power embedded computer concepts that are consistent with that architecture and can meet SWaP and extreme environmental requirements | Priority 5 |

LOW-COST DATA ACQUISITION SYSTEMS

- | | |
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| • Leverage SBIR to a radiation-tolerant low-cost data acquisition system technology, then secure program funding for post Phase II commercialization | Priority 6 |
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Conclusions



- The highest priorities for advanced avionics are:
 - Continued investment in High Performance Spaceflight Computing (HPSC), and underlying technologies
 - Continued investments in crew interfaces
- The next priority should be development of interconnect technologies to enable avionics architectures that address increasing sensor bandwidth, and can leverage the increased compute capabilities provided by HPSC
- Other priorities include development of radiation-hardened multi-output POL converters, development of low power embedded computers to support distributed robotics architectures, and development of low-cost, robust, high-accuracy data acquisition systems to enable distributed in situ monitoring of structures and subsystems on cost constrained missions
- Additionally, opportunities should be sought to leverage SBIR/STTR to address lower priority gaps

Acronyms



- AI – Artificial Intelligence
- ASIC – Application Specific Integrated Circuit
- COTS – Commercial off the shelf
- DAQ – Data Acquisition
- ECLSS – Environmental Control and Life Support System
- EDL – Entry, Descent, and Landing
- ESDMD – Exploration Systems Development Mission Directorate
- EVA – Extravehicular Activity
- GPP – General Purpose Processing
- GPU – Graphics Processor Units
- HI – Heterogeneous Integration
- HPSC – High Performance Spaceflight Computing
- HUD – Heads Up Display
- ISRU – In Situ Resource Utilization
- LEO – Low Earth Orbit
- LPEC – Low Power Embedded Computer
- LSII – Lunar Surface Innovation Initiative
- LuSTR – Lunar Surface Technology Research
- NEPP - NASA Electronics Parts and Packaging Program
- NESC – NASA Engineering & Safety Center
- NRE – Non-recurring Engineering
- PALETTE – Planetary and Lunar Environment Thermal Toolbox Elements
- POL – Point-Of-Load
- REALM – RFID Enabled Autonomous Logistics
- RFID – Radio-frequency Identification
- RHBD – Radiation-Hardened By Design
- SBC – Single Board Computer
- SBIR – Small Business Innovation Research
- SEE – Single Event Effect
- SMD – Science Mission Directorate
- STMD – Space Technology Mission Directorate
- STTR – Small Business Technology Transfer
- SWaP – Size, Weight, and Power
- TX – Taxonomy